The Machines Behind Precision Optics

Optical Fabrication of Aspheric and Freeform Mirrors

Tech. Days
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Outline

- Quad Chart
- DOD Contracts
- NASA SBIR Task Statement
- Optical fabrication equipment
- Freeform Surface Fabrication
- Surrogate Tapered Cylinder Definition
- Grinding Process Summary
- UltraForm Finishing (UFF)of Freeform Surfaces
- UltraSmooth Finishing (USF)
- UltraSurf metrology
- Phase II Plan & Commercialization

Small Business Innovation Research

Optical Fabrication and Metrology of Aspheric and Freeform Mirrors

OptiPro Systems, LLC
Ontario, NY

INNOVATION

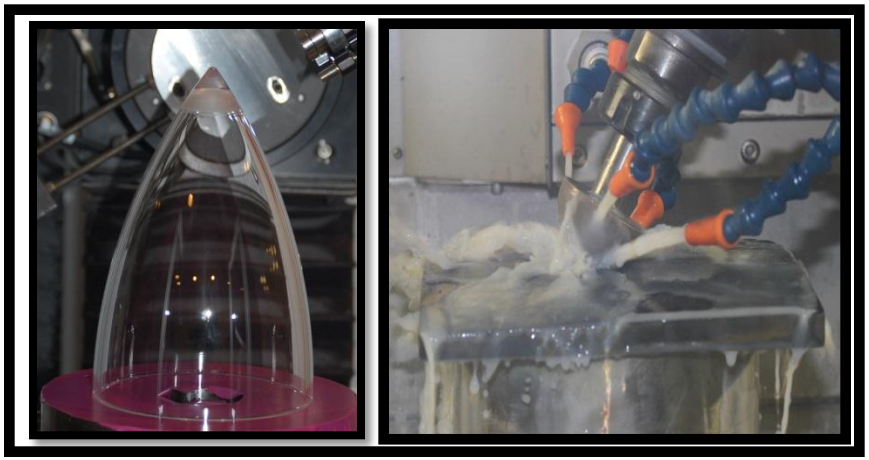
The UltraForm Finishing (UFF) and the UltraSurf platforms developed by OptiPro Systems deterministically polish and measure complex aerodynamic and conformal shapes made of difficult to manufacture glass, crystal and ceramic materials.

ACCOMPLISHMENTS

- 2008 OSA – Paul Forman "Excellence in Engineering Award" for first affordable Computer Controlled Optical Machining Center.
- Optical fabrication companies and prime contractor suppliers are embracing the new technology to cost effectively manufacture axisymmetric domes and optics for newly designed defense systems. The technologies developed under the SBIR contracts have provided a cost effective manufacturing solution for DoE & DoD components.
- The integration of the UFF (CNC controlled finishing platform) and the UltraSurf (Automated non-contact measurement device) provides a deterministic fabrication solution for a wide range of newly developed windows , domes and mirrors.

COMMERCIALIZATION

- UltraForm Finishing (UFF) : Asphere, Axisymmetric Dome , Freeform Polisher
  - Private Sector installations at Universities, Material manufacturers and Precision optical component manufacturers
  - US Patent No. 7,662,024 B2 : "Method and Apparatus for precision polishing of Optical Components"
- UltraSurf : Non-Contact Asphere, Axisymmetric Dome measurement platform
  - Private Sector Asphere and Dome Measurement System for production
- Primary market focus is on companies engaging in the optical fabrication and measurement of spherical domes, aspheres, parabolic mirrors, torics and conformal/freeform shapes.
- Private sector investment into the UFF and UltraSurf platforms has been through Beta site partners and production level machine purchases.
- OptiPro Systems, LLC has alliances with material manufacturing firms who require new manufacturing techniques to test and enhance their prototype components and determine the pathway to production level quantities



Tangent Ogive and Tapered Cylinder

GOVERNMENT/SCIENCE APPLICATIONS

- NASA Contract Number NNX12CF49P
- DOD Contract Numbers W31P4Q-05-C-R048 and W31P4Q-04-C-R101 awarded by the Defense Advanced Research Projects Agency (DARPA); and Contract Numbers N41756-05-M-1390, N68936-06-C-0010 and N68936-09-C-0079awarded by the Navy Engineering Logistics Office and NAVAIR.
- Toric , Acylinder and other freeform geometric shapes made from Si and SiC.
- Freeform reflective mirror application for the Department of Energy
- Materials Include : Spinel, ALON™, CeraLumina™ , Si, SiC, ceramics & standard optical glasses

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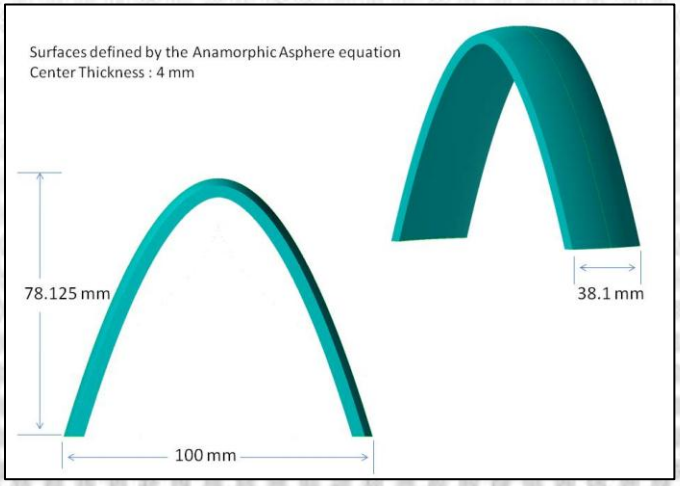
Date : August 01, 2012

NAVAIR SBIR Contracts

- Conformal Sensor Window
  - Contract N68936-09-C-0079
- Metrology for Ogive Infrared Dome
  - Contract N68936-10-C-0094

Objective

Demonstrate the grinding, polishing, final finishing, and metrology of conformal corrective infrared-transmitting optics and the companion aerodynamic domes such as a tangent ogives and near hemispherical domes.



NASA SBIR Task Statement

Description

Deterministic computer numerically controlled (CNC) grinding and polishing techniques are being developed for precision fabrication of forming mandrels for x-ray mirrors and off-axis parabolic mirrors. The mirror's resolution depends on the mandrel quality and therefore requires minimal scatter due to mid spatial frequency errors. OptiPro proposed a rapid manufacturing technique for the forming mandrels and off-axis parabolic mirrors with a combination of deterministic grinding and polishing tools. First, the near cylindrical shape of the work piece will be generated via grinding, and finally polishing of the optical surface will be achieved by utilizing a compliant deterministic polishing tool called UltraForm Finishing (UFF). The UFF is a sub-aperture polishing technique that is designed to correct the localized deviation on the surface and to remove mid spatial frequency and axial figure errors resulting from the grinding phase (in the 2x10-5 to 1x10-1 µm-1 spatial frequency range).

Fabrication Requirements

During Phase I, OptiPro will work to fabricate a cylindrical shape, 200 x 200 mm, x-ray mirror mandrel or an off-axis parabolic mirror via a combination of deterministic microgrinding (DMG), a common practice in today's optical fabrication shops, and UFF polishing. Special tool path algorithms will be developed and polishing slurry/belt material combinations will be tested. The UFF's unique in-process metrology equipment will allow for better control of the polishing steps. In addition to OptiPro's grinding and polishing capabilities, our recently developed UltraSurf system (developed through a Phase II Navy SBIR) will be utilized for intermediate measurements during the fabrication process.

Technology Transfer

The development of a cost effective commercial process capable of fabricating freeform mirrors and optics for aerodynamic conformal windows with arbitrary shapes is paramount to program sustainability. Conformal windows with corrective optics could be used for synthetic vision systems on commercial aircraft. These windows could increase the pilot's field of regard and might be used in locations that would not be suitable for flat windows. New x-ray telescope systems in development, are reliant on precision optical surfaces with stringent accuracy requirements.

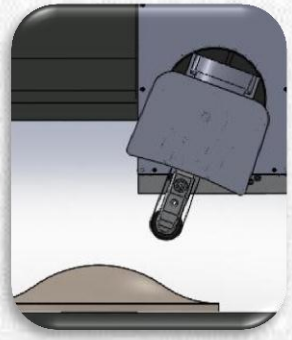
Optical Fabrication Equipment

eSX

ePX

UFF

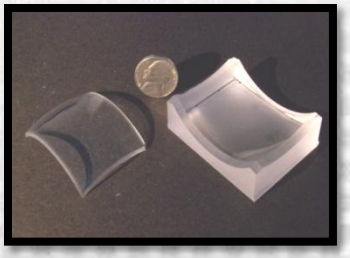
SXL / UFF 500



Dome

Ogive

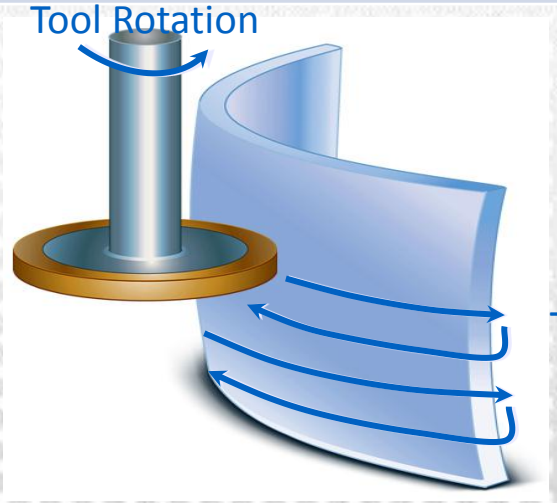
Conformal



Freeform Optics

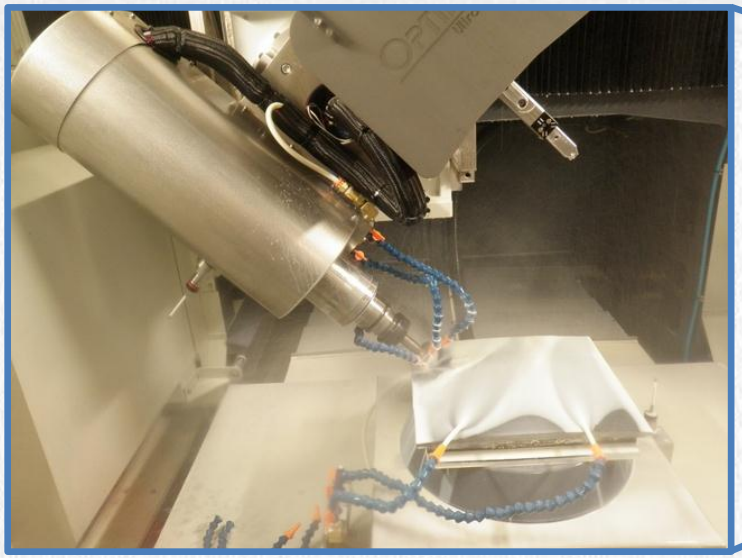
Optical geometries that are not rotationally symmetric, or ones that cannot be produced by rotationally symmetric manufacturing methods has led to the development of 3-5 axis processing solutions.

Raster Grinding	Raster UFF
For grinding, majority of parts can be ground with 3-axis motions by using different tool geometries and part mounting scheme's. 4&5-axis motions simplify the part mounting requirements.	For UFF there are limitations using 3-axis configurations because of limited tool geometry and belt directionality, which also affect the consistency of the removal function. Specifically in the R2 direction(See Picture Below).



Grinding Spinel Window Surface

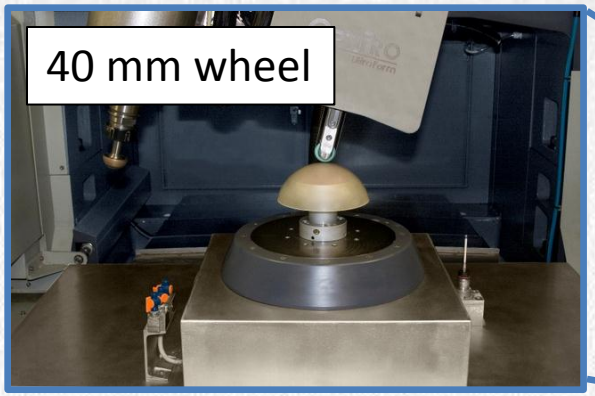
SXL 500

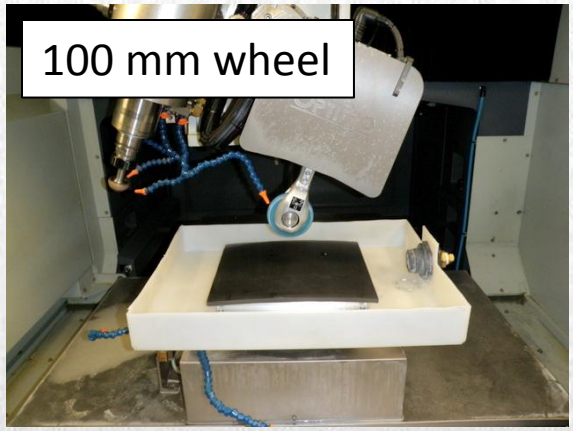


- Fused Quartz, Glass, Spinel, SiC, Si freeforms
- Capable of 5-axis simultaneous motion
- Ability to grind flats, spheres, aspheres, and freeform optical components
- Tool & part probing
- Custom programming / automation configurations available

UltraForm Finishing Dome/Freeform

UFF 500

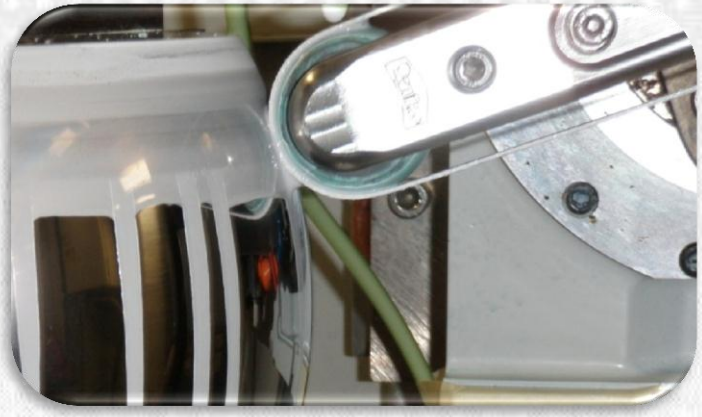


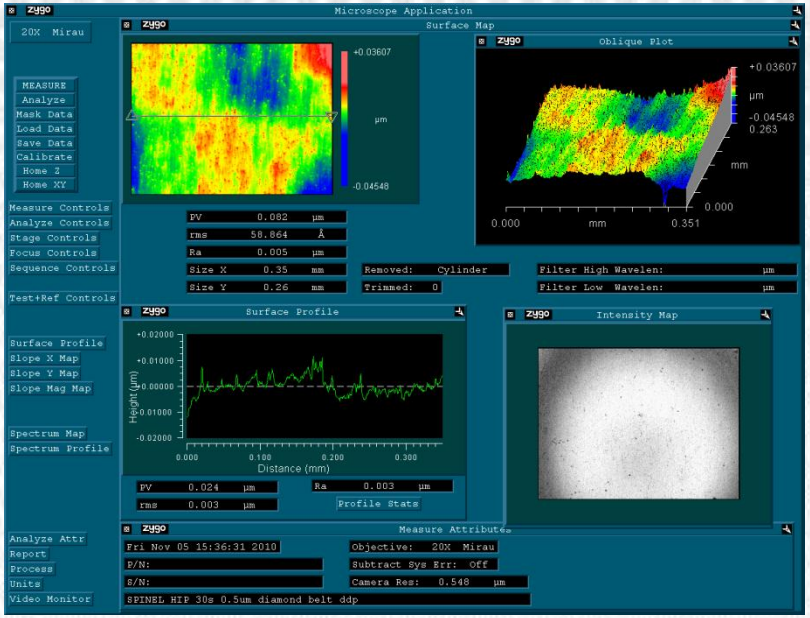


- Simple Windows based GUI
- Capable of 5-axis simultaneous motion
- Ability to polish flats, spheres, aspheres, cylinders, and freeform optical components

UFF Freeform Surfaces

Stainless steel mold finishing





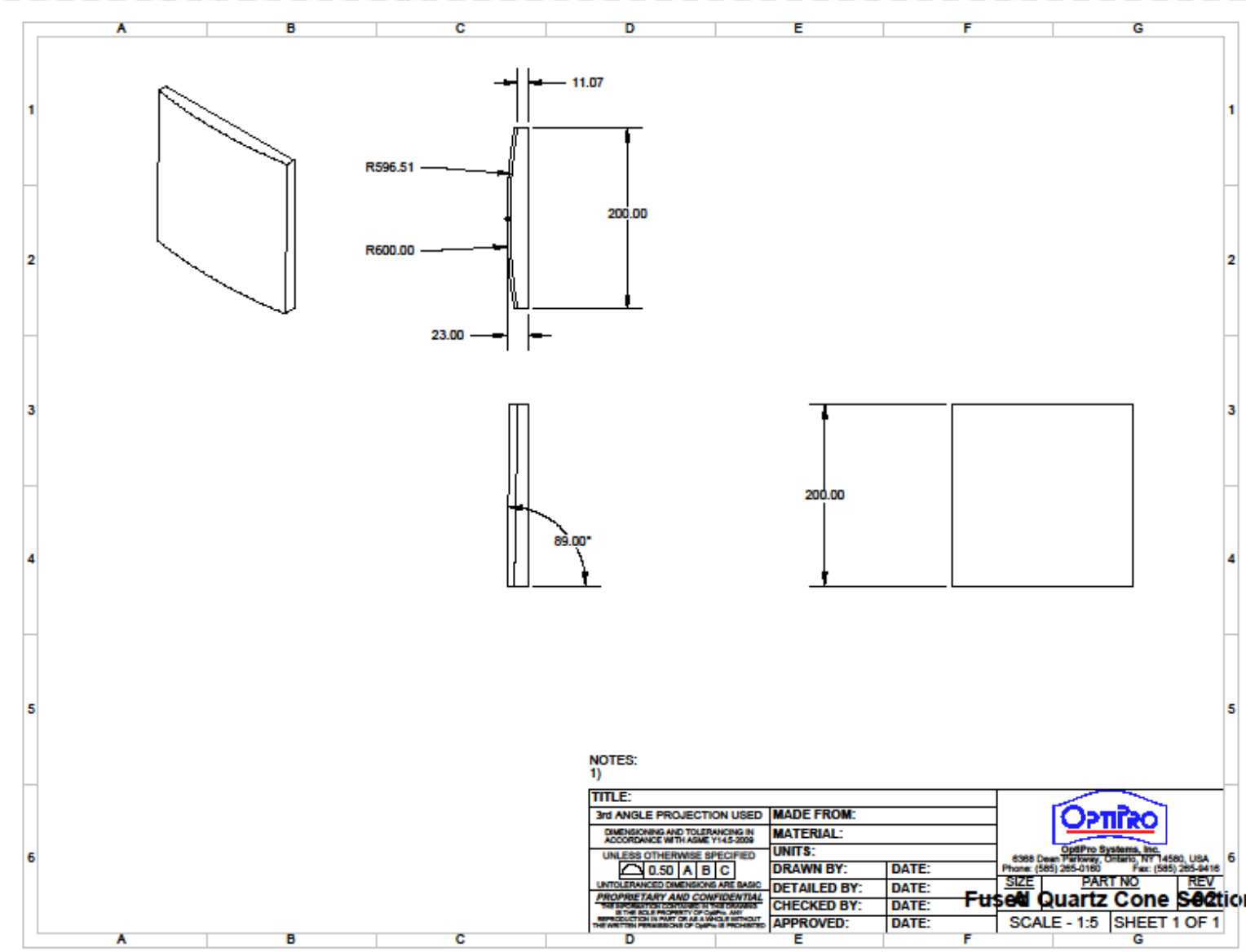
BK7 Glass Toroid finishing

SS Surface Finish NewView Results

- PV: 82 nm
- Ra: 50 Angstroms
- rms: 60 Angstroms

Aspheric Window

Tapered Cylinder Dwg



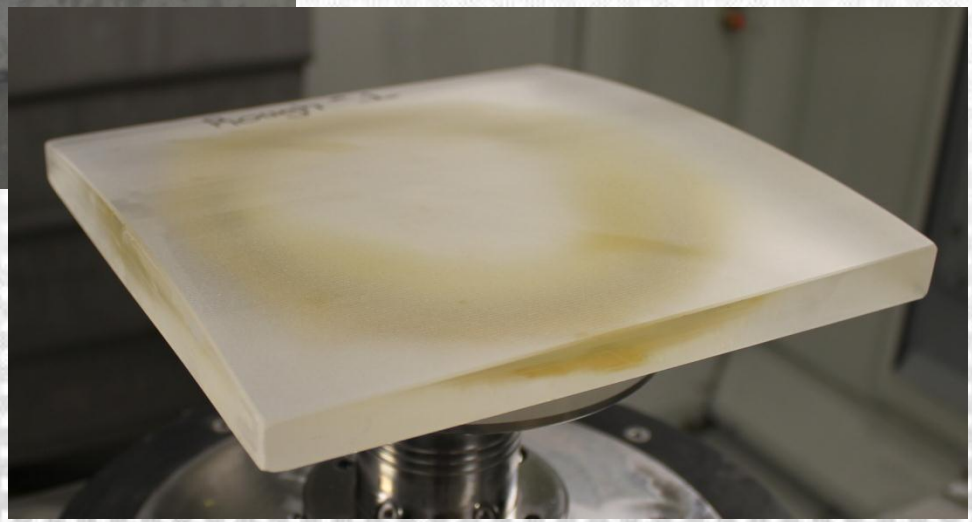
Tapered Cylinder Grinding Process

- Fused Quartz blank 210mm x 210mm x 25.4mm
- Plano surface ground with a 10/20 um diamond tool
- Tapered cylinder ground with freeform toolpath
  - MasterCAM
  - Custom toolpath generator
  - Machine Fagor Servo control parameters optimized
    - Feed forward gain
    - HSC – High Speed Contour
    - Corner rounding
  - R,M,F grind
    - 30 grit, 220 grit and 15um diamond
  - Tool spindle & Tool dressing

Tapered Cylinder Grinding

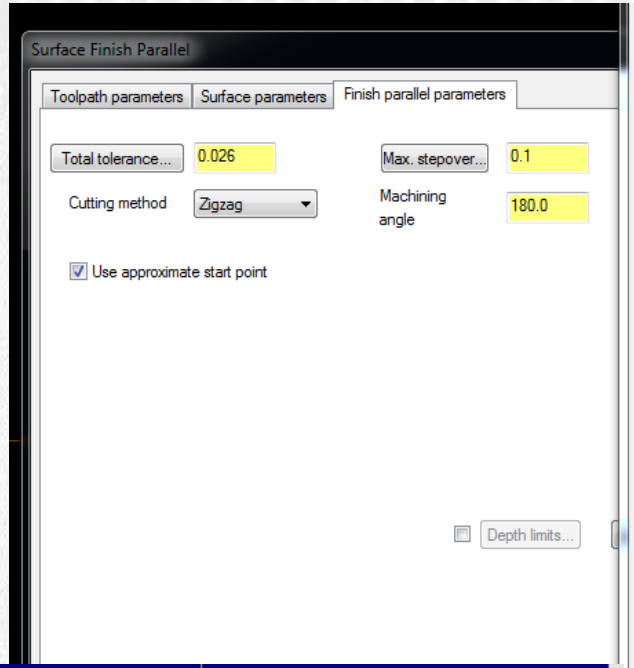
eSX 300 platform

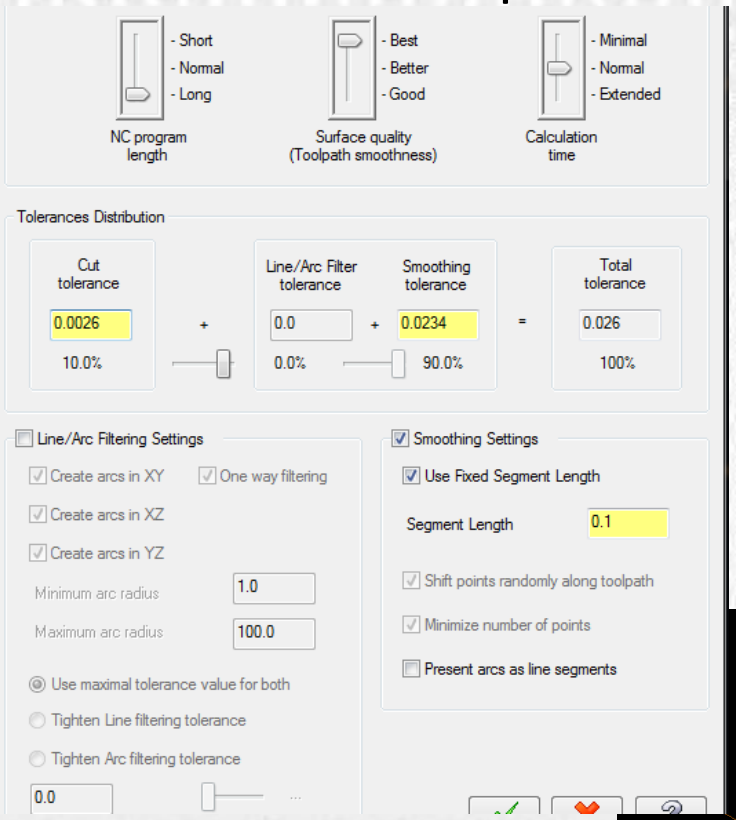
- Raster toolpath grinding
- Metal Bond tooling
- Blaser B-Cool coolant

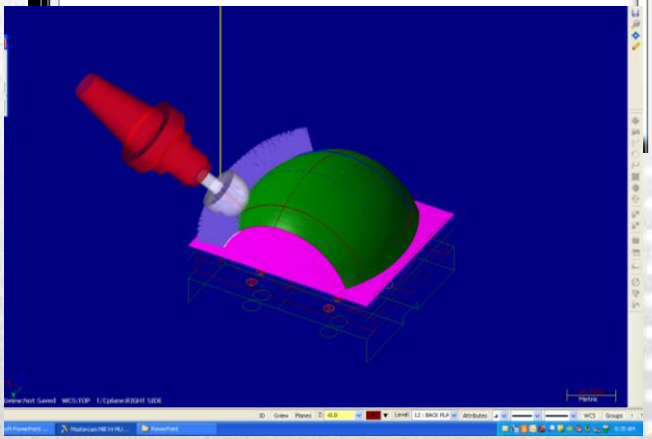


Integration with MasterCam

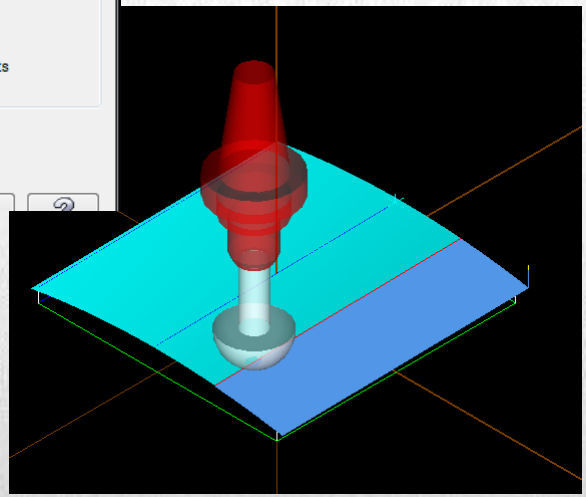
MasterCam Creates the Multi-axis tool paths for fabrication.





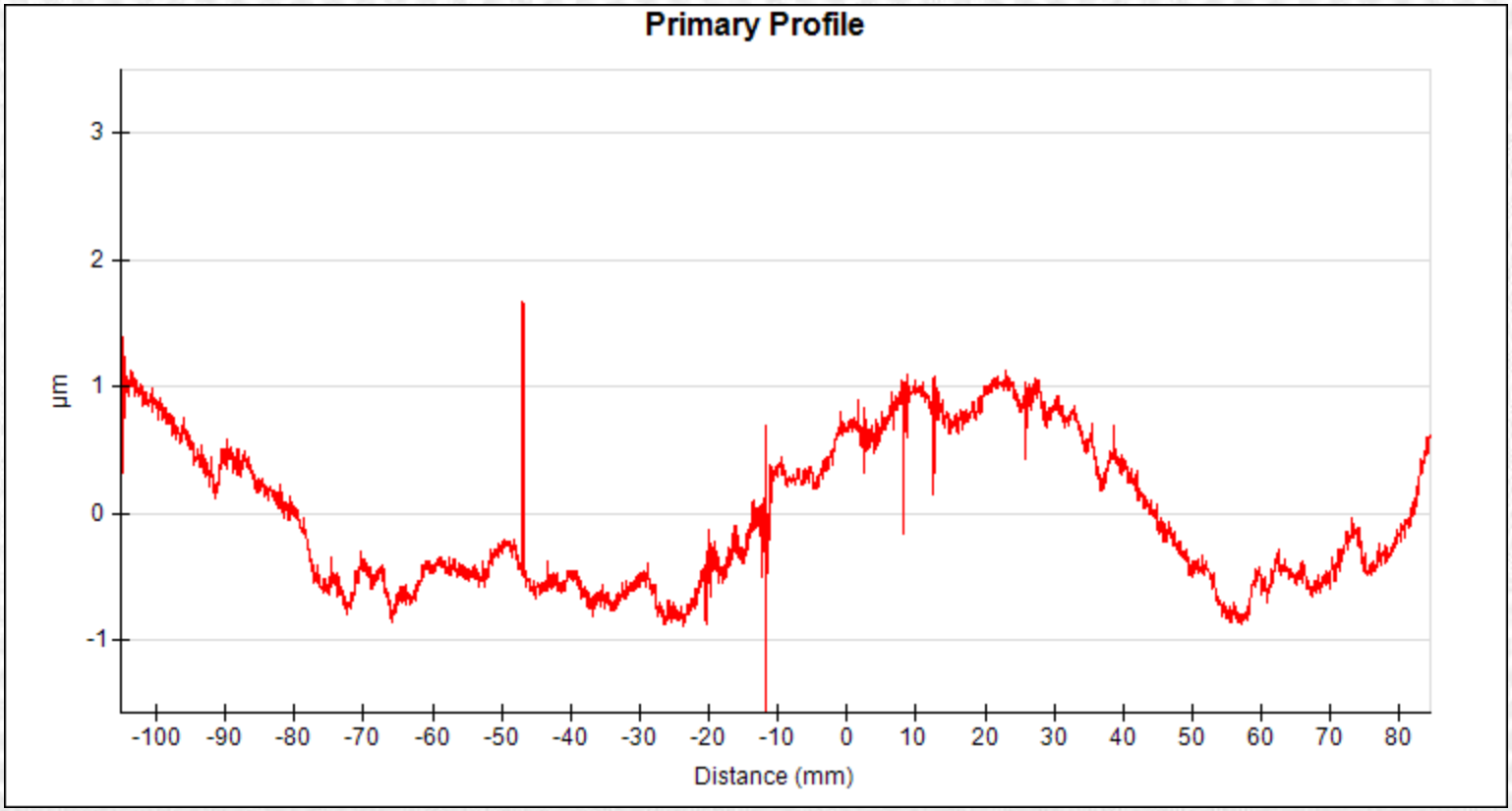


Integrating OptiPro's platforms into MasterCam was a critical step in free-form tool path generation and testing.



Profile Scan After Fine Grind

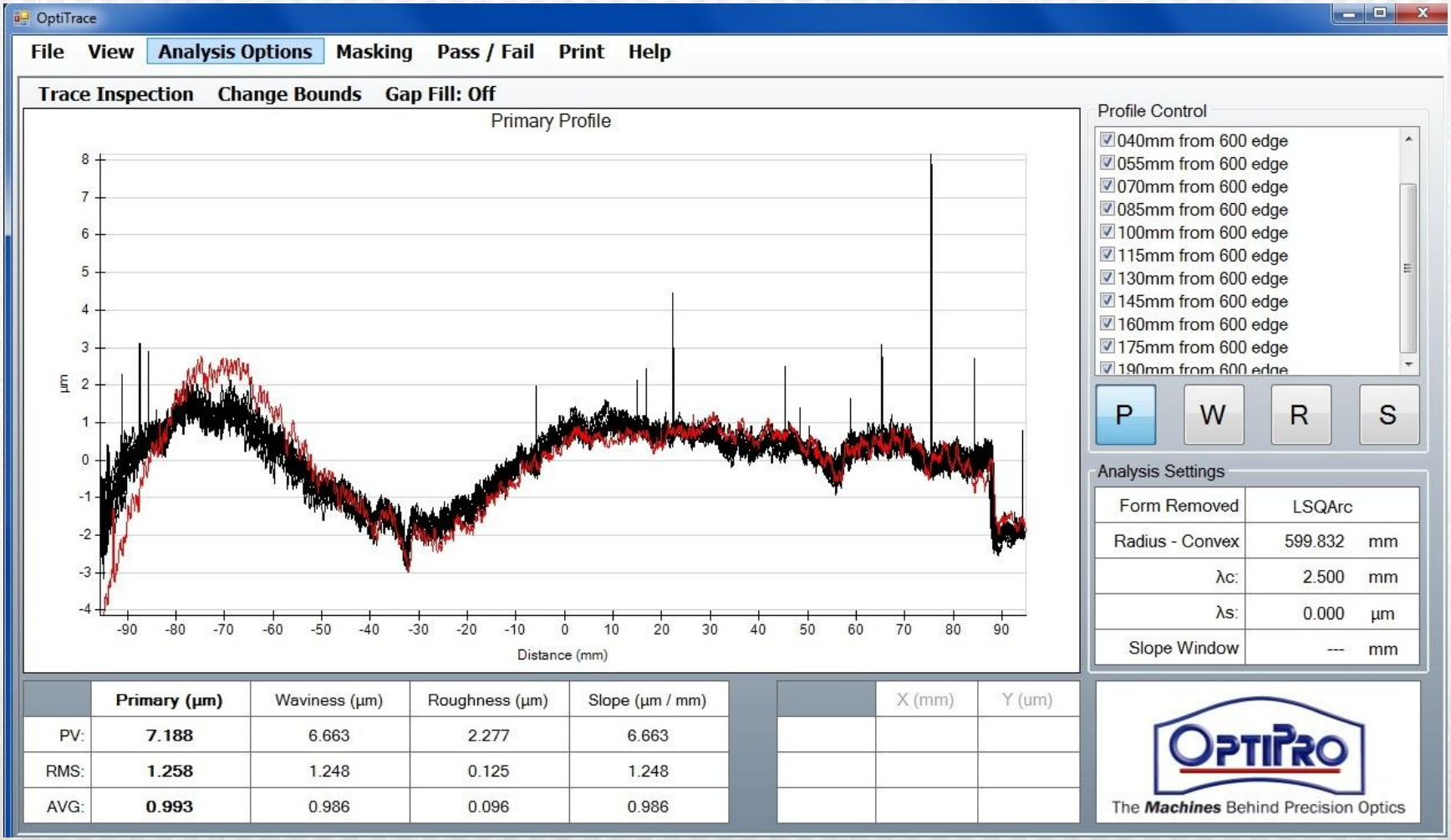
Profile is taken in the along direction.



Primary Profile, unfiltered

Surface Profile Scan Analysis

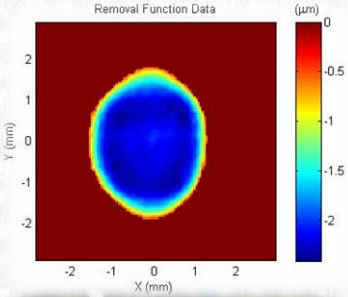
- Contact profilometer scan across the grinding toolpath direction



UltraForm Finishing (UFF)

Deterministic sub-aperture CNC polishing

10 to 300 mm optics: Flats, spheres, aspheres and freeforms



Measure Removal Function

- Integrated STIL pen
- Onboard metrology

Input Initial Figure Error

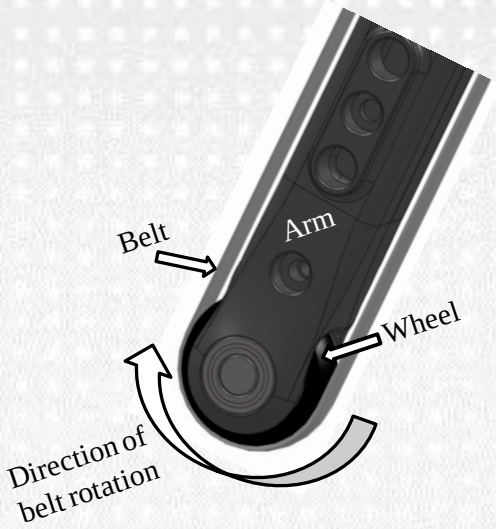
- Zygo Interferometer Input
- Profilometer Input

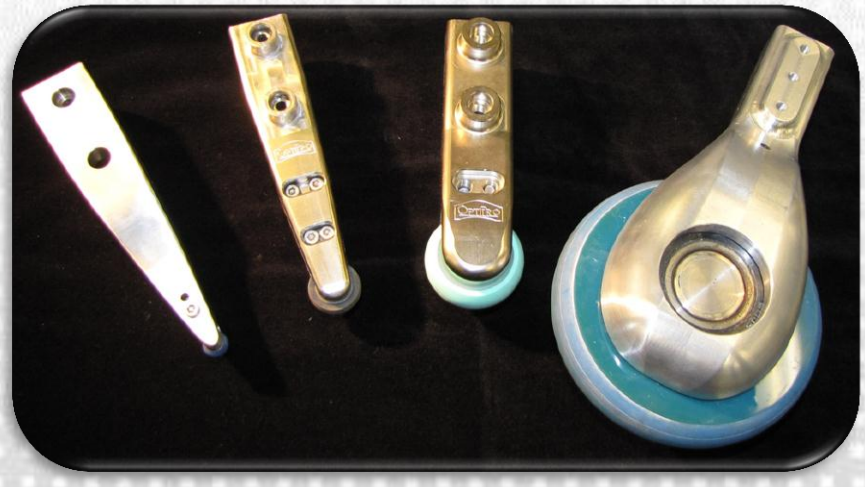
Optimize Polishing Tool Path

- Reduce figure error
- Fine control of polishing path

UFF features

- 5-axis CNC controller with simple to use GUI
- Wheel size range from 8 to 100 mm in diameter
- Wheel nominal hardness range from 30 to 80 Shore A
- Bound/fixed abrasives or commercial polyurethane belts with slurry
- Capable of finishing a wide range of materials from optical glass to hard ceramics and metals to sub-micron form tolerances.



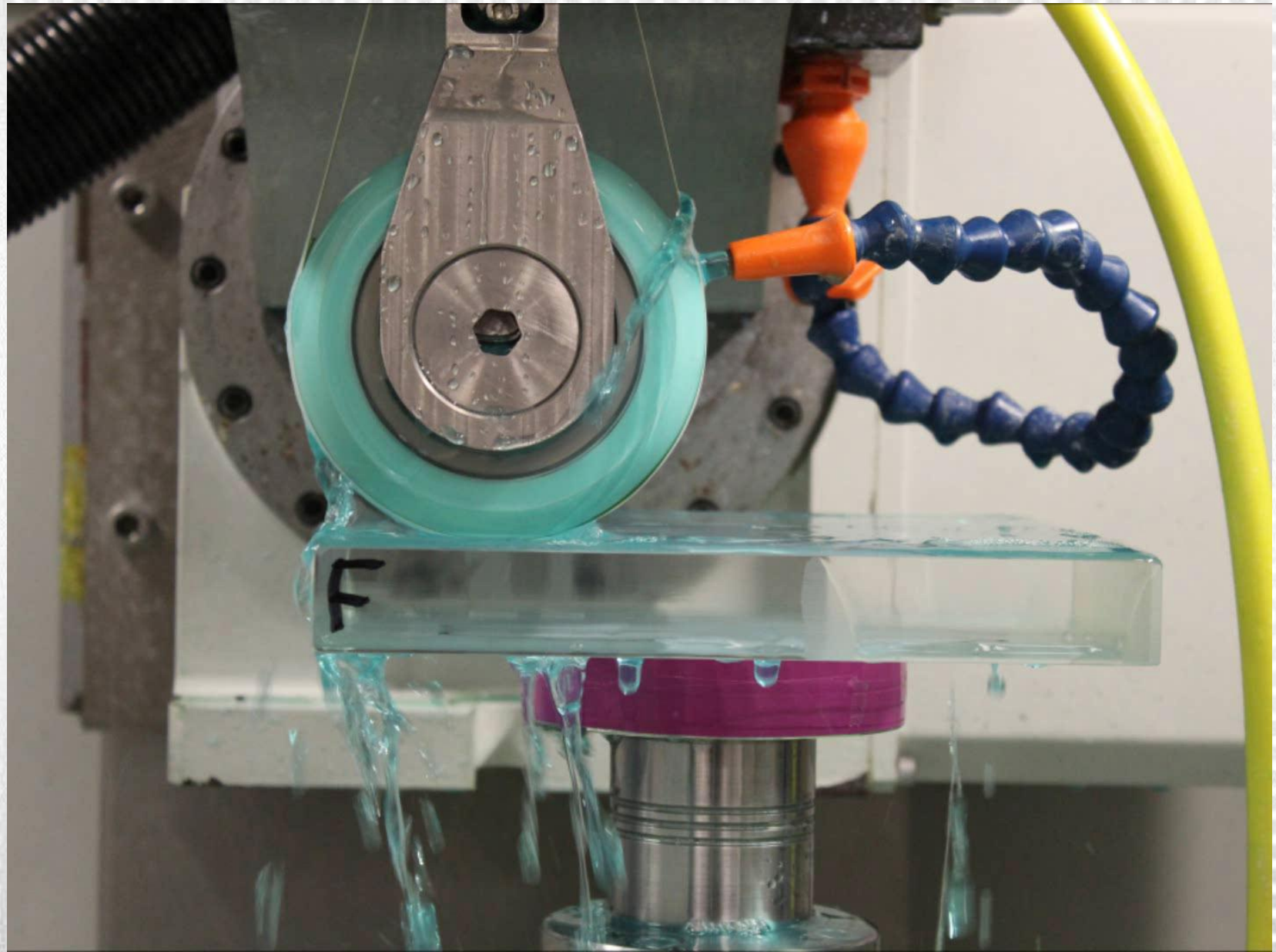


4” UltraWheel Durometer Types

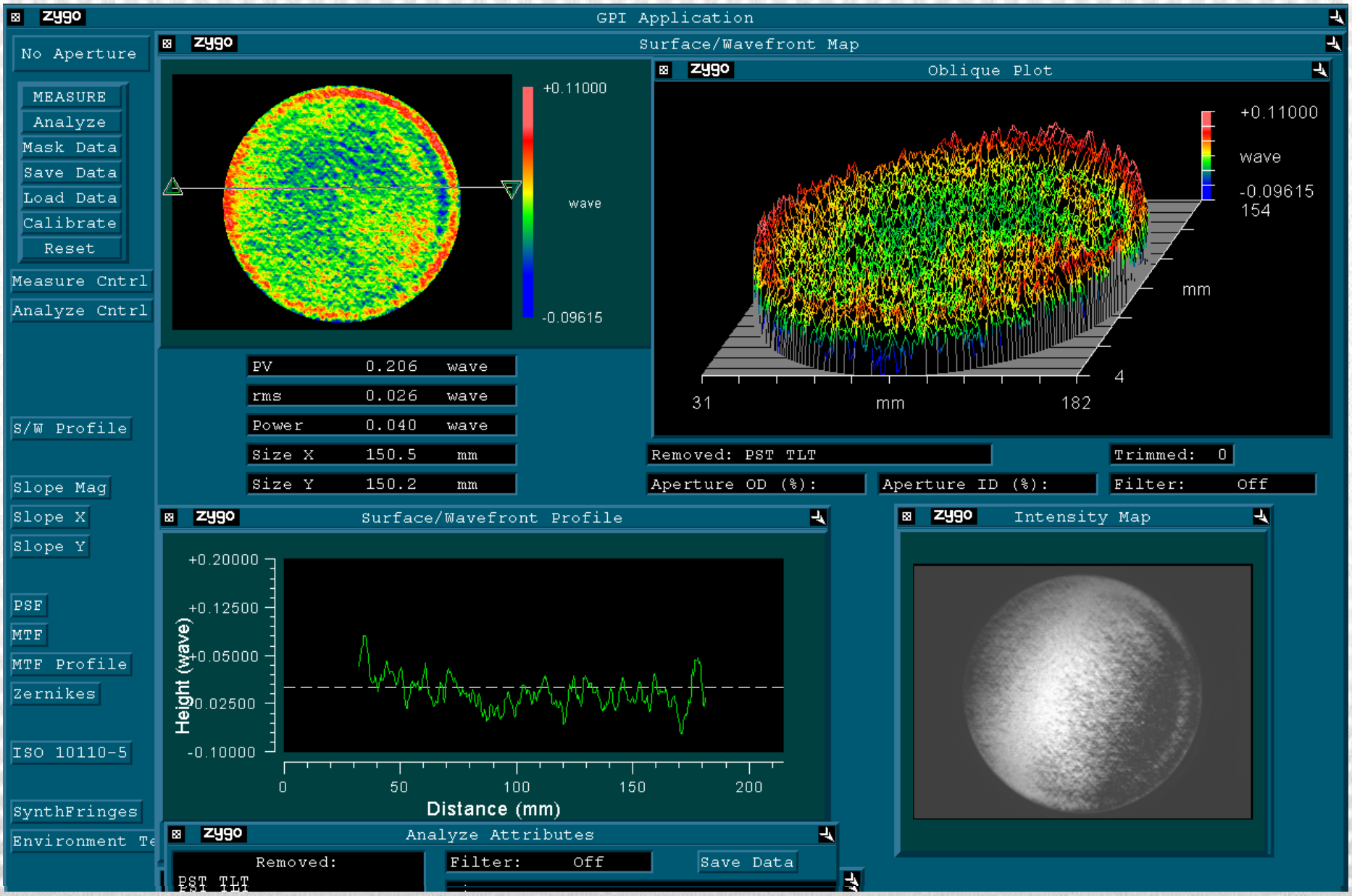
Using Shore A Durometer Scale:

Softer 30A 40A 50A 60A 70A Harder

4” UltraWheel Technology

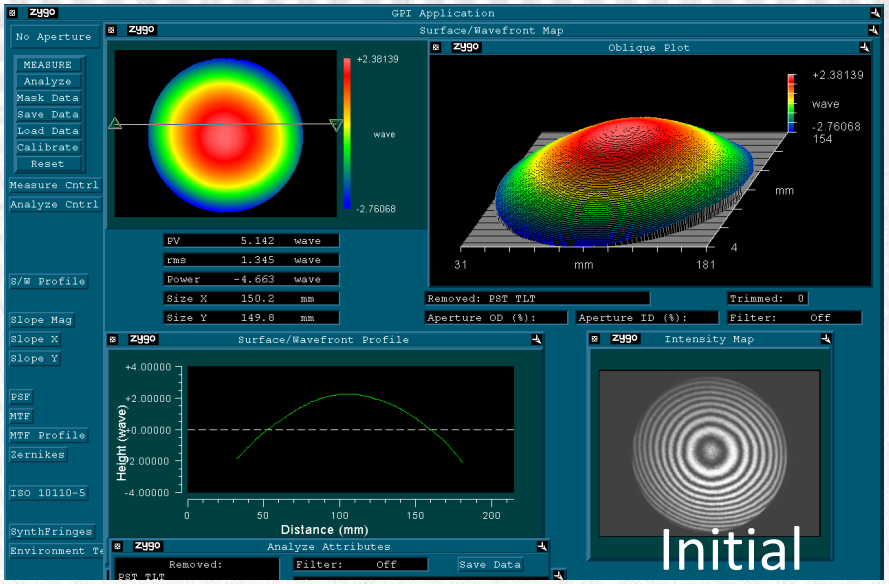


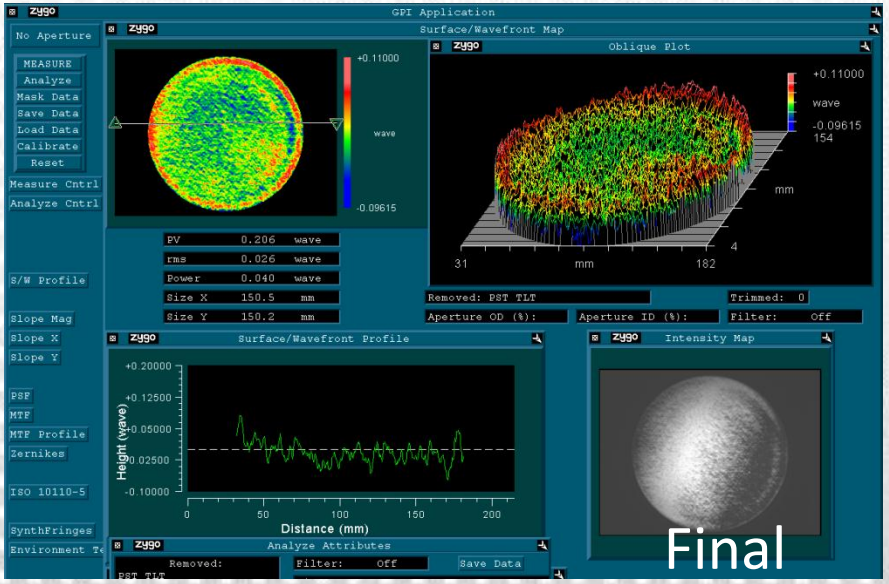
Results Using 70A Durometer UltraWheel



Results Using 70A Durometer UltraWheel

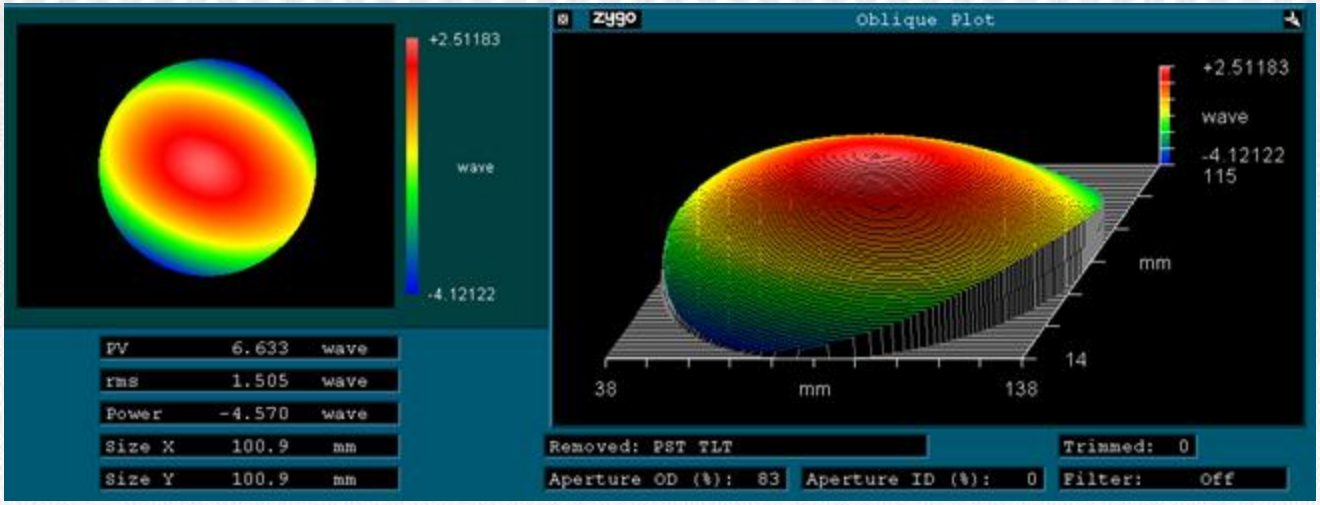
- Material: Fused Quartz
- Shape: Plano
- Diameter: 6”
- Belt:polyurethane belt
- Cerium oxide slurry
- Total polish time: About 7 hours from a 12um grind



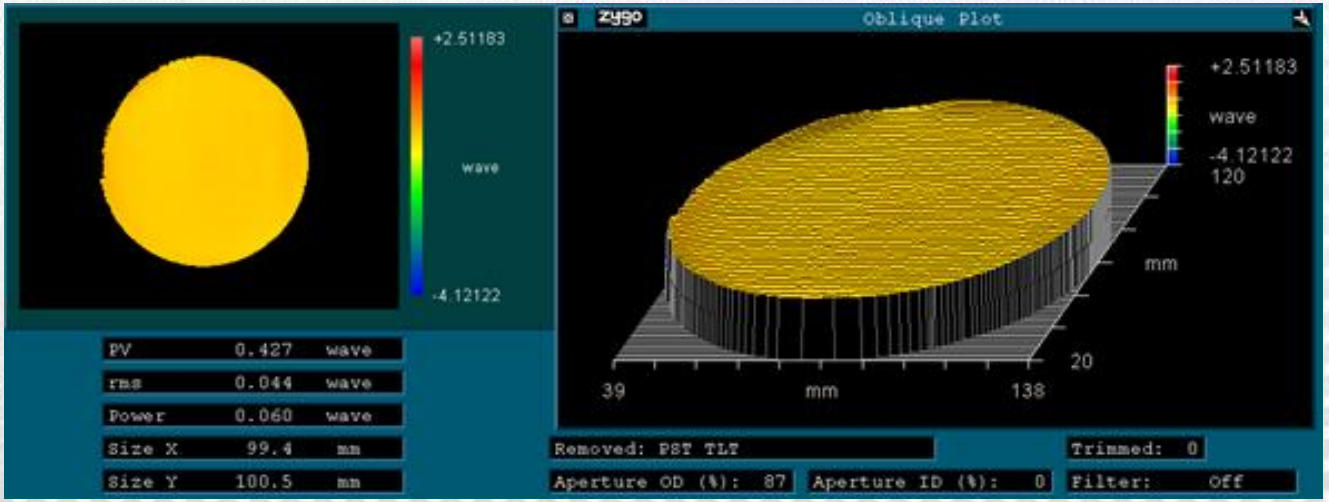


UFF 100mm diameter Sapphire

- A -Plane Sapphire that was prepolished.
- 100mm Clear Aperture.
- 3um Diamond Slurry.
- 100mm diameter, 70 Durometer UltraWheel.
- Polyurethane Belt.
- Polishing was performed in 4, 3hr figure correction runs.

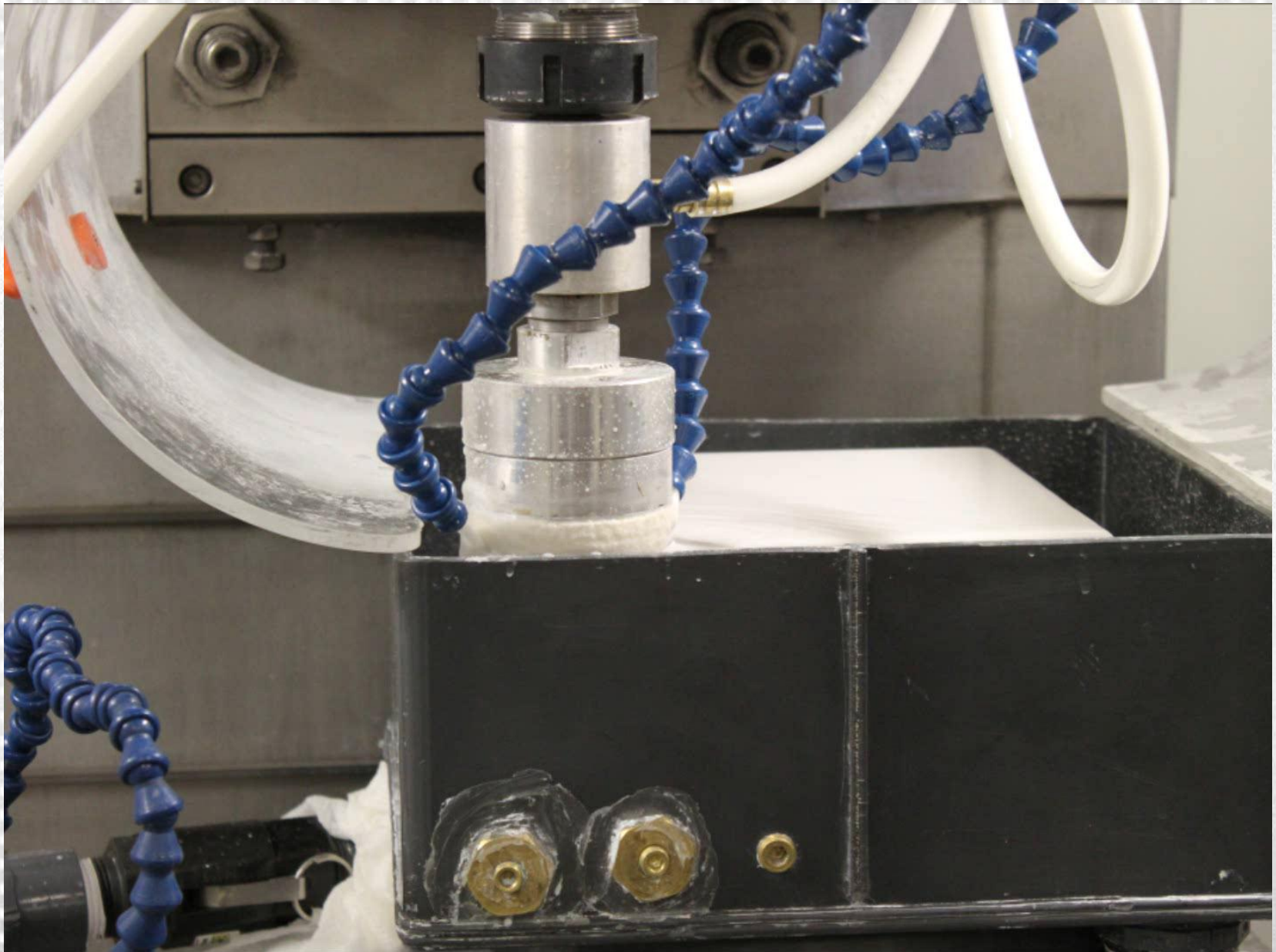


Initial PV – 6.6 λ



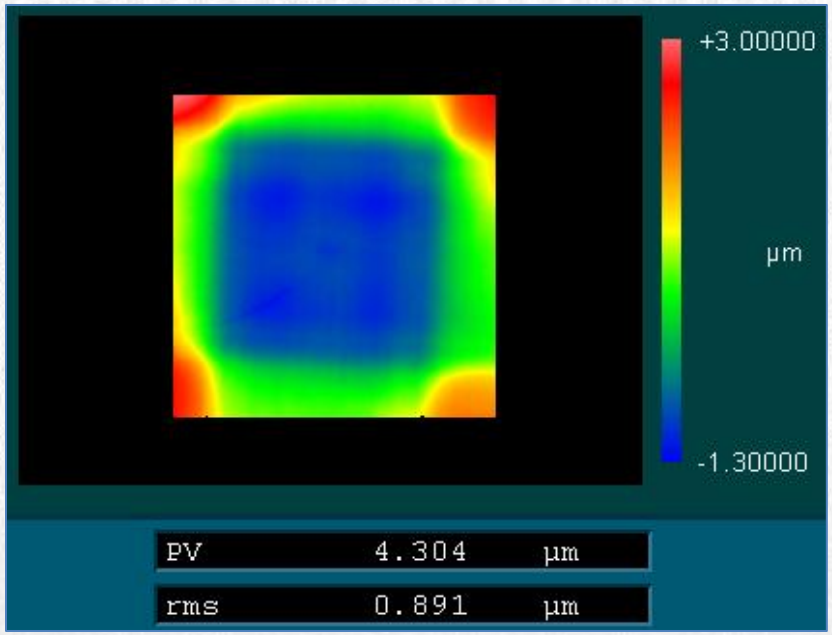
Final PV – 0.4 λ

UltraSmooth Finishing (USF) Technology

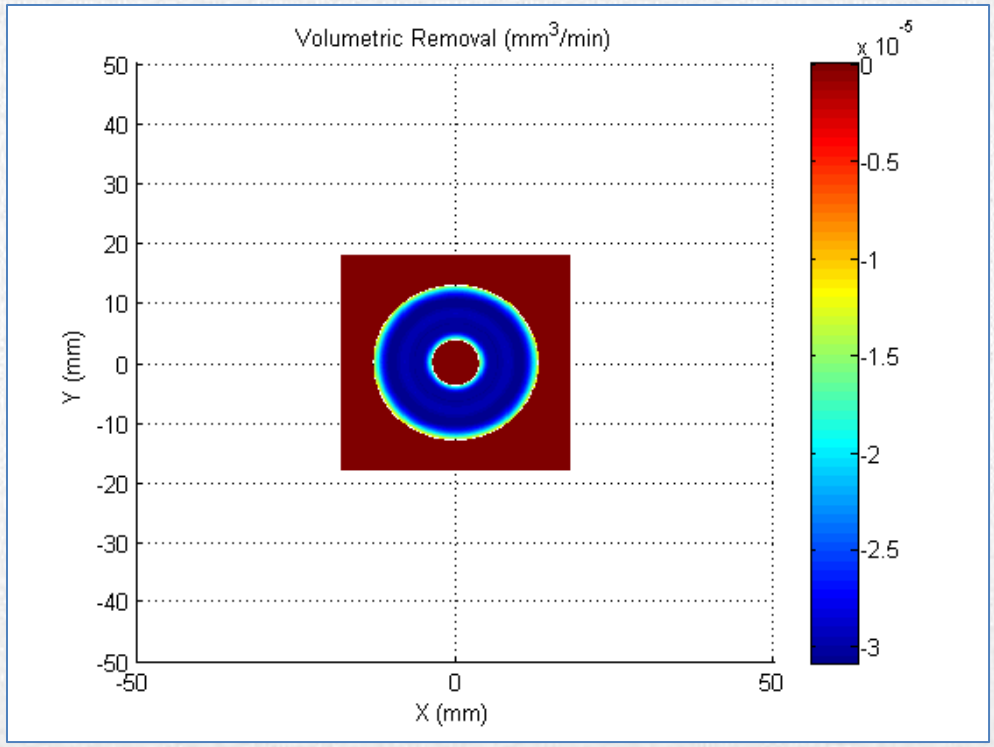


USF Results

Material is a 100 mm x 100 mm plano BK7 window that is 6.35 mm thick.

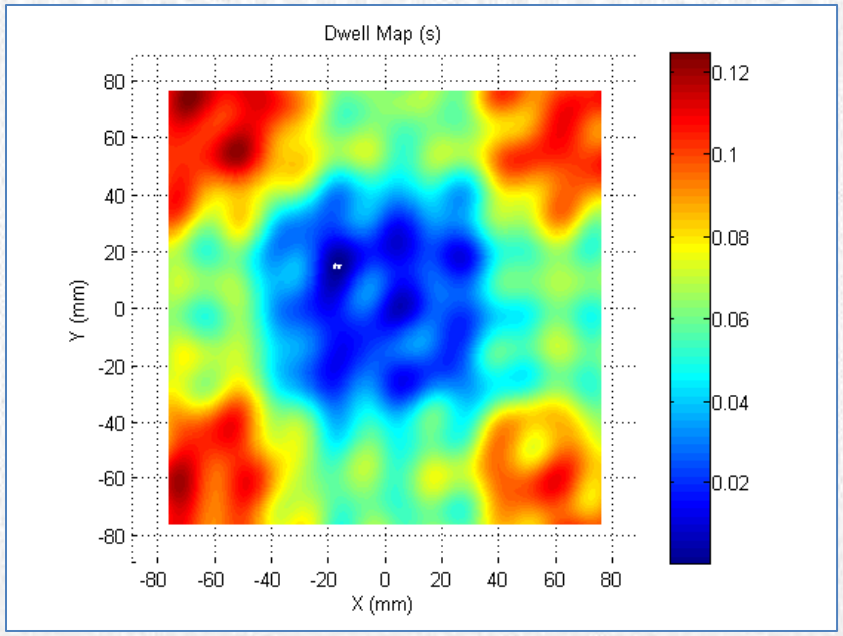


Zygo GPI image of initial surface

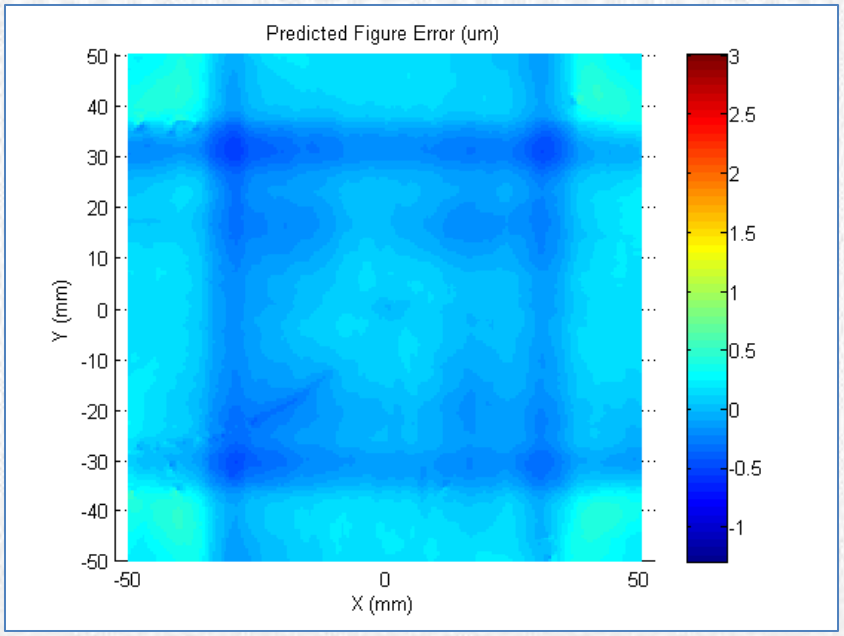


3D removal function from a profilometer trace

USF BK7 Results (cont.)

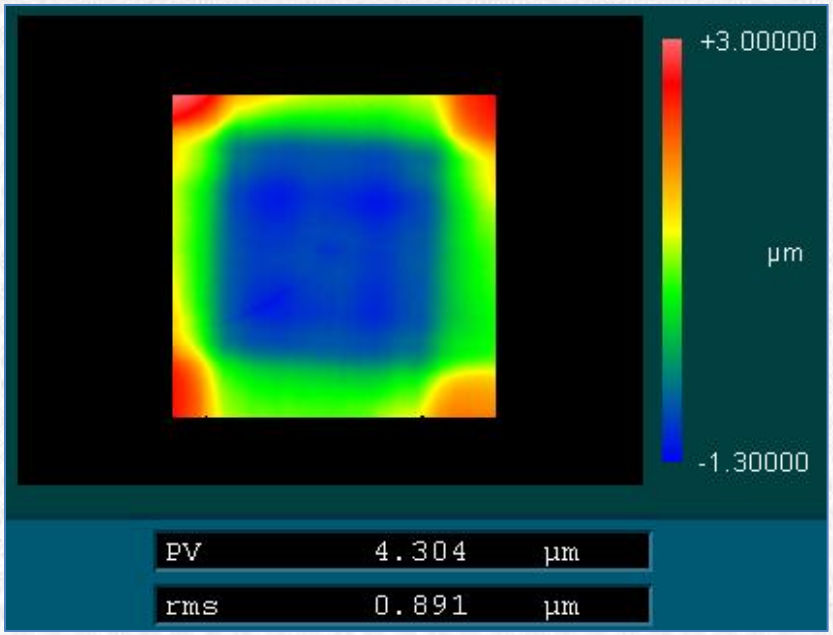


Computed dwell map for correction routine

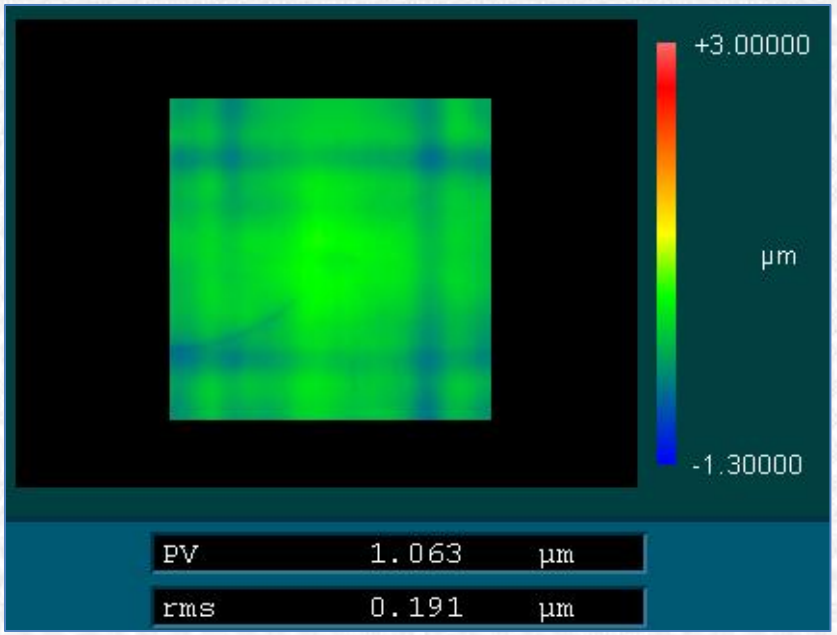


Predicted image after polishing predicted pv of ~1 micron

USF BK7 Results (cont.)



Zygo GPI image of initial surface



Zygo GPI image of final surface

The result was ~75% correction in one pass, and ~90% convergence rate with the predicted image.

UltraSurf

non-contact 3D measurement system

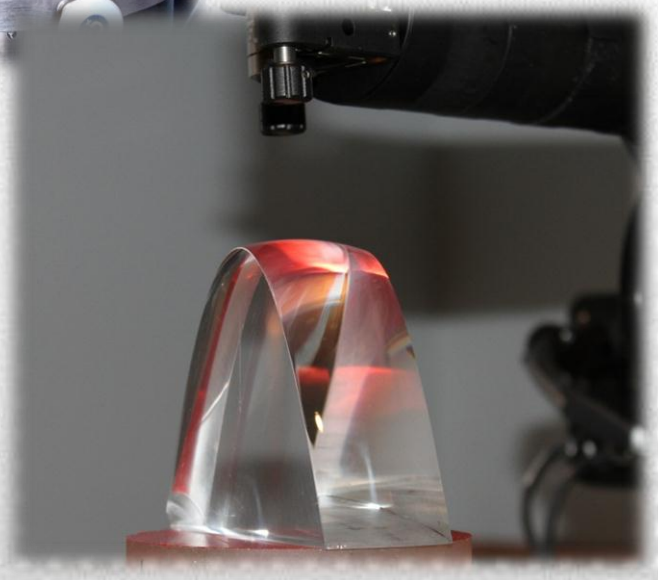
Plano

Spherical

Aspherical

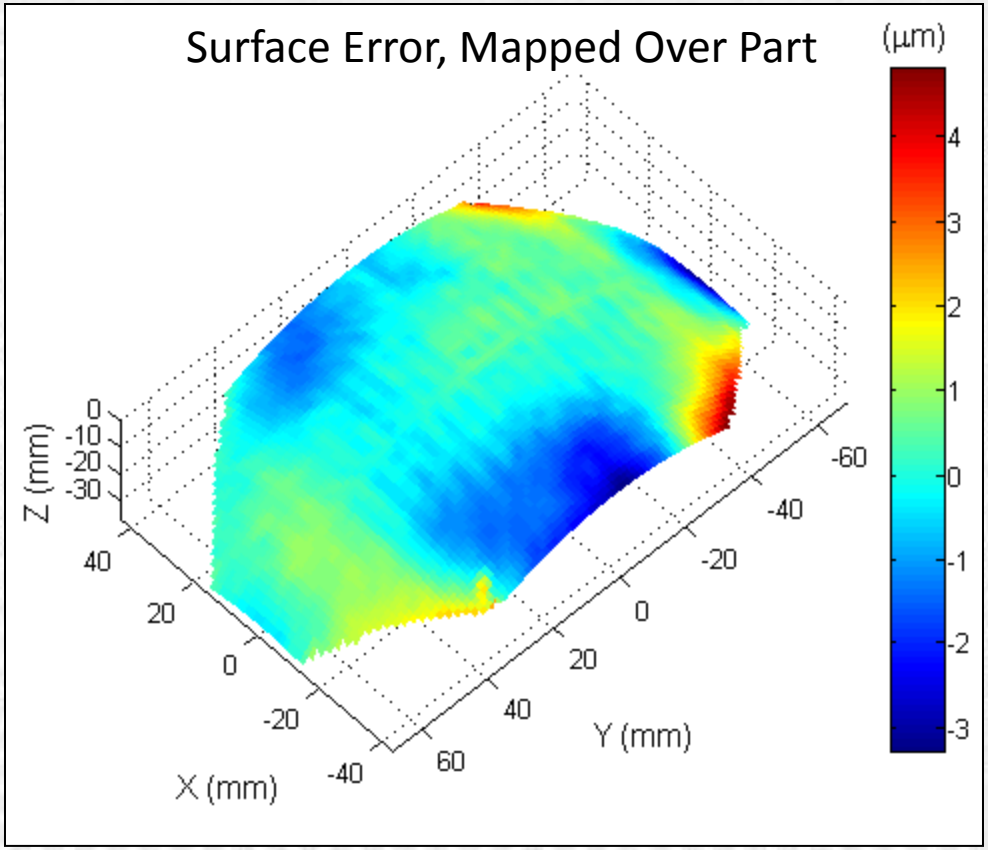
FreeForm

Thickness map



- Can accommodate multiple non-contact optical sensors
- 5-axis air bearing system
- Linear motors
- Brushless DC rotary motors
- X,Y,C position the part
- Z,B position the probe

Stainless Steel Torus



Phase II

- Optimization of the surface definition
- Demonstrate scalability of the process
- Tool path correction automated interface
- Grinding tool wear reduction/compensation
- Reduction in polishing cycle time
- Optimize the UFF and USF process to further reduce mid spatial frequencies
- Provide on board metrology for large workpieces

Commercialization

- The Advanced Process Development (APD) laboratory is an extension of our Small Business Innovative Research projects developed for the U.S. Department of Defense and NASA. Focused to develop cost effective process solutions for prototype optical components and production requirements.
- Our team of scientists, engineers and opticians develop fabrication solutions that are easily transferred and implemented at the customer's facility.
- Multiple DOD and Prime Contractor programs.
- OptiPro Systems develops and offers a full product line of precision optical fabrication and metrology equipment, built in the USA.
- Teaching advanced CNC optical fabrication courses and seminars utilizing the latest technologies.

OPTIPRO

The **Machines** Behind Precision Optics